Volume I

Chapter V

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of the sun

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V - The Methods of Study of the Sun

1 - Actinometry

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erved intensities of the solar radiation and the altitudes of the place of
ervation above the sea level.

Table 1

Place of the observation	The altitude above the sea level in m	Observed intensity of the solar radiation in cal/cm² min
[illegible]	0	[illegible]
Agra	220	[illegible]
Davos	1 590	[illegible]
Mt. Wilson	1 740	[illegible]
[illegible]	3 460	[illegible]
Mt. Whitney	4 420	[illegible]
Balloon	8 500	[illegible]
Balloon	22 000	[illegible]

This table shows, that the solar constant is approximately [illegible]

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V - The Methods of Study of the Sun

1 - Actinometry

At present, in many places on the Earth, daily observations of the intensity of the solar radiation are made. These studies are of a great interest to the astrophysics, in connection with the computation of the so called, "solar constant" - the intensity of the solar radiation beyond the limits of the terrestrial atmosphere.

The solar constant is the quantity of energy, expressed in gram-calories that is received, during 1 minute, by an area of 1 cm^2, placed perpendicular to the solar rays, beyond the limits of the terrestrial atmosphere, at the mean distance from the Earth to the Sun.

In the computations of the solar constant from the observational data, a correction is introduced for the absorption of the light in the terrestrial atmosphere. The greater the altitude of the point of observation is above the sea level, the less is the thickness of the mass of the air, penetrated by the solar rays, and therefore, the less is the absorption. Table 1 lists the observed intensities of the solar radiation and the altitudes of the place of observation above the sea level.

Table 1

Place of the observation	The altitude above the sea level in m	Observed intensity of the solar radiation in gr-kal/cm^2/min.
Kolberg	5	1.41
Agra	555	1.48
Davos	1 600	1.59
Mt. Wilson	1 740	1.64
Jung frau	3 460	1.63
Mt. Whitney	4 420	1.72
Balloon	7 500	1.76
Balloon	22 000	1.89

This table shows, that the solar constant is approximately 2 gram-calories

unacc.

/cm^2 -min.

The measured intensity of the solar radiation also depends upon the altitude of the Sun. The higher is the Sun's altitude, the shorter is the ray's path through the terristrial atmosphere and the smaller is the absorption.

Fig. 62 shows the intensity of the solar radiation in relation to the mass of the air, that is penetrated by the rays, according to the observation made in Calama, Chili on March 11th 1920. The mass of air laying above sea level, and penetrated by the ray vertically, is taken as the unit.

The determination of the solar constant is possible only by an extrapolation beyond the limits of the terrestrial atmosphere of the observed intensities of the solar radiation, for different masses of the air, penetrated by the rays. Such extrapolation still presents great difficulties and the resultant values of the solar constant still contain small systematic errors.

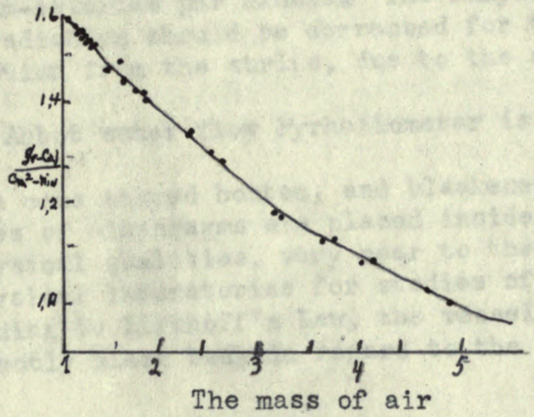


Fig. 62

1 - The Pyrhelimeter

The intensity of the solar radiation is measured by an apparatus, called the Pyrhelimeter. Every pyrheliometer consists of two principal parts: a blackened body, absorbing the solar rays and of an apparatus that records the rise of temperature caused by these rays.

The pyrheliometers are divided into two classes: the standard and the secondary. The first, the most complicated in construction and in use, measure the intensity of the solar radiation in gram-calories per 1cm^2 for 1 minute, while the latter, the simpler in construction and more convenient to use, are required to furnish only the relative values of different readings.

The Compensated Pyrheliometer of Angstrom and The Water Flow Pyrheliometer of Abbot are used as the standard instruments. The diagram of the first is presented in Fig. 63.

Its principal part consists of two thin strips A and B, of Manganese, Alloy that are blackened on one side. The difference of their temperatures is measured by the thermo-element N, with the aid of the Galvanometer G. The current from the cell S may be passed through either of the plates, at will, and its intensity is regulated by the resistance coil and the rheostate R. The instensity of the current is measured by the same Galvenometer G. WW_1 - is an appliance for changing the sensitivity of the galvanometer G.

For making a measurement of the intensity of the solar radiation, one of the strip A or B is subjected to the action of the solar rays, while the other remains in the shade. The thermo-element registers the difference of the temperatures of the two strips. Then, by passing the electric current through the strip, that remained in the shade, this strip is heated to the temperature of the other strip. In this case the thermo-couple produces no more current, and the electric current is measured at that point.

If F - is the area of the strip, i - the intensity of the current in amperes, r, the resistance in ohms, then the intensity of the solar radiation E, in gram-calories per $1cm^2$ per minute can be found from the formula: $E = 14.34\frac{i^2r}{F}$, where the coefficient 14.34 is used for the conversion form joules per second to gram-calories per minute. The computed values of the intensity of the solar radiation should be corrected for the errors due to the loss of energy by reflection from the strips, due to the specific heat etc.

The diagram of the Abbot water flow Pyrheliometer is shown in Fig. 64.

A vessel AA, with a cone shaped bottom, and blackened inside, receives the solar rays. A series of diaphragms are placed inside of the vessel, and thus make it, in its physical qualities, very near to the absolutely black body that is used in physical laboratories for studies of the laws of radiation. Therefore, according to Kirkhoff's Law, the vessel AA, must possess the qualities of a perfectly black body in regard to the absorption of the radiant energy.

The absorbed radiant energy heats the water that envelopes the vessel AA, being admitted to the jacket H through the inlet E, and flowing out through the tube F. The temperature of the water at the intake is measured by an electric thermometer D_1, and at the outflow by the thermometer D_2.

Both thermometers consists of two thin platinum wires, that vary their electric resistance with the changes of the temperature. The four platinum wires of the two thermometers form the branches of a wheatstone Bridge. A weak current is passed through both thermometers and a galvanometer registers the difference of the resistances of the branches of the Wheatstone Bridge. Knowing the resistances of all parts of the circuit, as well as the temperature coefficient of the resistance, it is possible to compute the difference of the temperatures of the water at the intake and the outflow, from the reading of the galvanometer. This, in turn, will allow the intensity of the

solar radiation to be computed which is admitted into the apparatus through the diaphragms BBC. In order to lessen the losses of the heat, the whole apparatus is placed inside of a Dewar Vessel having double, silvered sides, with the air evaluded from the space between the double sides.

Abbot has also constructed a water pyrheliometer of another type, which he called The Waterstir-Pyrheliometer, where the apparatus was filled with a measured amount of water, that is stirred by an electric motor during the measurements. In other respecta this apparatus is analogous to the one, just described. The variation of the temperature of the water is also measured by a Platinum Thermometer.

For systematic studies of the intensity of the solar radiation, pyrheliometers of the secondary type are used, but their scales are graduated with the aid of Standard Pyrheliometers.

This type of apparatus includes the Silver Disk Pyrheliometer and the V. A. Michelson's Ice Pyrheliometer.

The first of these instruments utolized a blackened silver disc, with a mercury filled chamber within it, as the receptor of the solar energy. A sensitive thermometer, that allows readings to 0.01° is immersed in the mercury.

The intensity of the solar radiation is determined in numbers, proportional to that intensity, and that express the increase of the temperature of the silver disc for a definite period of time of the work of the pyrheliometer.

The Ice Pyrheliometer of V. A. Michelson is constructed on the principle of Bunsen's Ice Calorimeter. The solar rays heat a black body, that transfers the heat to the ice and water that surround it. This causes a part of the ice to melt, and consequently the volume, occupied by the ice and water decreases. This decrease of the volume is registered by a capillary tube, whose water level goes down.

C. S. M. Pouillet was first to construct a pyrheliometer in 1838 and he has found the solar constant to be 1.76 gramcal per 1 cm^2 per min. In the extrapolation of the measured intensities of the solar radiation beyond the limits of the terrestrial atmosphere, he made use of the law that was discovered, independently by Bouguer and Lambert in 1760. (See Chapter III, Part 1).

If E is the measured intensity of the solar radiation, and E_0 is its intensity beyond the limits of the terrestrial atmosphere, and m is the mass of air, penetrated by the solar rays, assuming the mass of air penetrated by the vertical ray to be 1, the formula of Bouguer will be

$$E=E_0a^m,$$

where α is the quantity called the coefficient of transparency of the atmosphere. As was demonstrated by Forbes, Radau, and particularly by Langley, the formula of Bouguer is true only for monochromatic light, but not for the integrated light of the Sun.

Hagen, Violle, Crovat, Sheiner, Gansky and other investigators tried to compute the solar constant by a simple extrapolation of the observational data, or by the Puillet method, but the computed values were not dependable, and the errors ranged from 1.7 to 4 gr-cal/cm^2/min^{-1}.

Langley used another method. He combined the observations made with a pyrheliometer with the observation by a new apparatus, designed by him - the spectrobolometer.

§2 - The Spectro-Bolometer, and the Langley-Abbot Method of Measurements of the Solar Constant.

The spectro-bolometers allow the curves of the distribution of the energy in the solar spectrum to be constructed, as it is observed with different masses of air penetrated by the Sun's rays. However the distribution of the energy in the solar spectrum is expressed by quantities proportional to the energy. By measurement of the area of the curve and by comparison with the corresponding value of the intensity of the solar radiation obtained by an observation with a pyrheliometer, the coefficient for the conversion of the readings of the spectro-bolometer into the units of energy is computed.

If we have a number of curves of the apparent distribution of energy in the solar spectrum for different masses of air penetrated by the radiation we can construct the curve of the distribution of energy beyond the limits of the solar atmosphere. Actually, by applying the Bouguer - Lambert formula $E\lambda = E_{o}\lambda \ \alpha_{\lambda}^{m}$, to a narrow part of the spectrum, which is entirely permissible, we can find the intensity E_o , of this part beyond the limits of the solar atmosphere. The area of the curve, plotted for a number of values of E_o will determine the desired solar constant. Langley's method, as well as the spectro-bolometer were improved upon by Abbot and his collaborators.

The spectro-bolometer consists of three principal parts: a spectroscope, that diffracts the solar rays into a spectrum; a bolometer, that is a highly sensitive electrical thermometer with a photographic registration of the readings of a galvanometer, and drive a clock which rotates the prism of the spectroscope, and simultaneously, moves the bolometer itself, along the spectrum. Fig. 65 shows a diagram of the apparatus.

The spectroscope consists of the slit r, a quartz prism g, a plane mirror p, reflecting the light to the concave mirror m, that forms the image of the spectrum on the bolometer n.

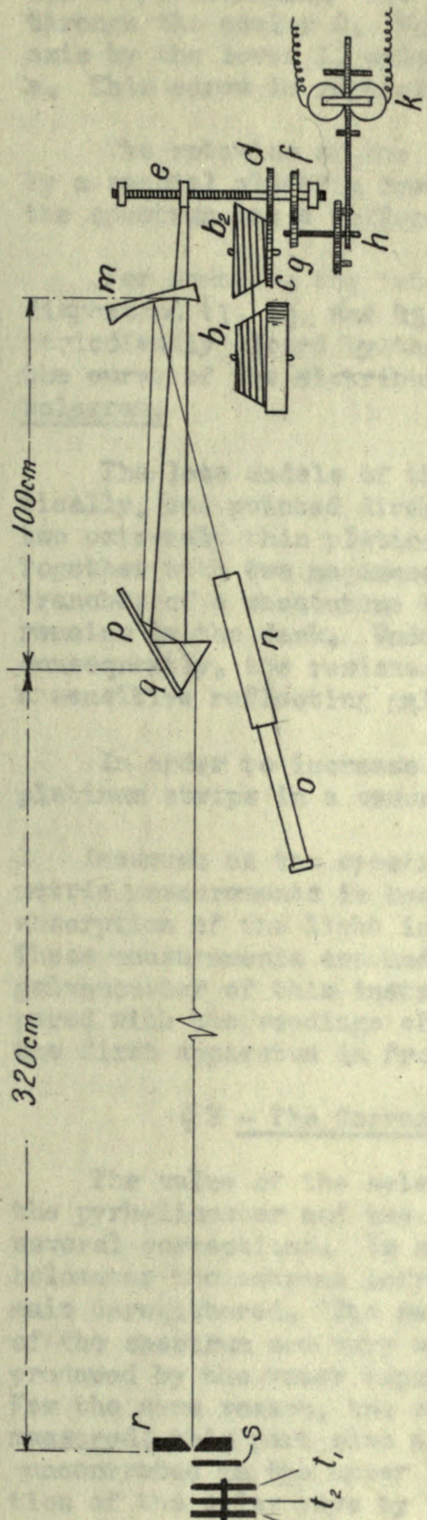


Fig. 65.

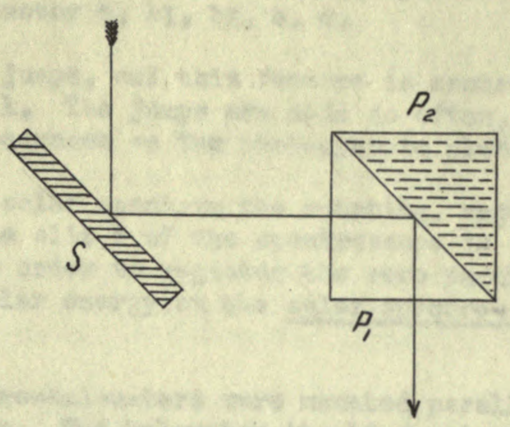


Fig. 67.

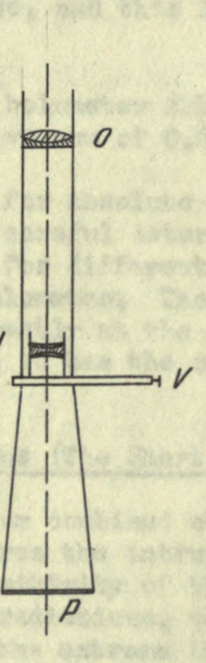


Fig. 68

The mirrors are made of the "Magnalia" alloy containing 31^{o}/o Magnesium and 69^{o}/o Aluminum. The position of the spectrum is controlled by the observer through the ocular O. The prism g is rotated with the mirror p around its axis by the lever l, which in turn is brought into the motion, by the screw e. This screw is rotated by the clock motor a, b1, b2, c, d.

The rotation of the screw e is by jumps, and this feature is controlled by a special electric breaker f, g, h, k. The jumps are made so often, that the spectrum has a uniformly smooth appearance on the photographic plate.

For changing the intensity of the solar spectrum the rotating, sector diaphragms t_1, t_2, and t_3 are used. The slit r of the spectroscope is periodically closed by the shutter s in order to register the zero point of the curve of the distribution of the solar energy on the solar spectrobologram.

The late models of the Abbot Spectro-bolometers were mounted parallactically, and pointed directly to the Sun. The bolometer itself consists of two extremely thin platinum strips, with an electric resistance of 3 ohms eaud. Together with two maganese wires, of 54 ohms resistance, they form the fourt branches of a wheatstone Bridge. One of the strips is lighted, while the other remains in the dark. Under the influence of the light, the temperature, and consequently, the resistance of one strip increase, and this is registered by a sensitive reflecting galvanometer.

In order to increase the sensitivity of the bolometer Abbot places the platinum strips in a vacuum glass vessel, with a vacuum of 0.0001 mm mercury.

I Inasmuch as the spectrobolometer is intended for absolute spectrophotometric measurements it becomes necessary to make careful determinations of the absorption of the light in the prism and mirrors for different wavelengths. These measurements are made by a second spectrobolometer. The readings of the galvanometer of this instrument, when pointed directly at the Sun, are compared with the readings of its galvanometer, when it has the spectral part of the first apparatus in fromt of the slit.

§3 - The Corrections to the Observations (The Short Method)

The value of the solar constant, computed from combined observations by the pyrheliometer and the spectro-bolometer requires the introduction of several corrections. In spite of the extreme sensitivity of the spectrobolometer the extreme infra-red and ultra-violet radiations, very often remain unregistered. The reason for this is, that the extreme infra-red parts of the spectrum are very weak, and contain many absorption bands which are produced by the water vapor and carbon dioxide of the terrestrial atmosphere. For the same reason, the extreme ultra-violet part of the spectrum can not be measured; this part also contains many absorption bands of ozone which is concentrated in the upper layers of the terrestrial atmosphere. The absorption of the solar rays by the ozone layer is so great, that the observable

spectrum of the Sun stops abruptly at 2900Å.

The corrections to the value of the solar constant for the unregistered extreme ends of the spectrum are computed, in part, from special studies of the infra-red part of the spectrum that are performed with very sensitive apparatus, and, in part, from the extrapolation of the distribution of energy in the solar spectrum, based on Planck's Law.

The observable infra-red region contains wide absorption bands (See Fig. 66), due to the water vapor and the carbon dioxide of the terrestrial atmosphere.

By plotting a smooth curve through the separate maxima of the curve of distribution of energy in the solar spectrum on the bologram, and by measuring the area between the smooth curve and the observed curve, it is possible to compute this correction.

The investigations of F. E. Fowle has demonstrated, that these corrections can be computed by a simpler method from the measurements of the ratio of the ordinates of the deepest part of the spectrum in the so-called, bands ρστ(9200Å) to the ordinates of the smooth curve. The correlation between the ratio of the ordinates and the correction is computed empirically once for all.

In summing up the above, we shall include a short description of the Langley- Abbot Method. Paralled observations are performed on two instruments: a pyrheliometer and a spectro-bolometer, 6 times a day for air masses penetrated by the solar radiation of from 1.3 to 5.0. From these observations a computation of the coefficients of the atmospheric transparency are made for about 40 parts of the solar spectrum.

Let I'_e be the observed intensity of the solar radiation at some moment, in reading of the spectro-bolometer, I_e be the area of the smooth curve plotted on the bologram, K_r the mentioned corrections, that account for the unregistered parts of the spectrum and K_s - the correction that accounts for the absorption bands in the infra-red part of the spectrum. We have

$$I'_e = I_e + K_r + K_s$$

By extrapolating beyond the limits ot the terrestrial atmosphere the intensity of the spectrum at the 40 points for which we have computed the coefficients of transparency for the day of the observations, we can sonstruct the curve of the distribution of energy in the solar spectrum beyond the terrestrial atmosphere, and determine its area, still expressed in the units of the graduations of the spectro bolometer. After the introduction of the correction for the unregistered parts of the spectrum, we have the integrated intensity of the solar radiation beyond the terrestrial atmosphere, I_o, expressed in the units of the spectro-bolometer.

If P is the reading of the pyrheliometer at the moment of the observation with the spectro-bolometer, and Δ- the distance from the Earth to the Sun, expressed in units of the mean distance, the solar constant is found from the formula

$$S = \frac{P.I_0}{I'_c}\Delta^2.$$

The refinement of the instruments and of the methods of interpretation of the observational data, have reduced the probable error of the daily computation of the solar constant to 0.9°/o. However, disregarding the high precision of the observations, the value of the solar constant have a yearly cycle, that point to some remaining, unaccounted for systematic errors. The daily determinations of the solar constant are of a vast importance in connection with the problem of the reality of the observed variations of the intensity of the solar radiation.

In 1919 Abbot proposed a new method, that does not require the numerous daily observations with the spectro-bolometer. This method, dubbed by Abbot "the short method" and based on the combined observations by pyroheliometer, spectro-bolometer and a new instrument, the pyranometer, has reduced the probable error of the daily observations to 0.4°/o.

The principal part of the pyranometer is a thermo-element, placed within a glass hood. With this instrument it is possible to measure the total radiation received by terrestrial objects, not only directly from the Sun, but from the sky as well. By obscuring the Sun by a small screen, so that its shadow falls upon the pyranometer, the radiation of the sky alone, can be measured.

The observations have revealed that the intensity of the radiation by the sky, near the Sun, depends upon the coefficient of transparency of the atmosphere at the moment of the observation. Abbot has determined, empirically, from a number of series of the simultaneous observations by a spectro-bolometer and a pyranometer a simple correlation between the coefficient of transparency of the atmosphere and a certain quantity F for different zenith distances of the Sun. The quantity F is computed by the formula

$$F = \frac{H\Psi}{P},$$

where H is the intensity of the radiation of the sky near the Sun, P is the reading of the pyrheliometer, and Ψ is the area of the absorption band according to the data of the spectrobolometer. Thus, having one measurement with a pyrheliometer, one simultaneous observation with a pyranometer, and one bologram produced simultaneously by a spectrobolometer, we have all the data needed for a computation of the solar constant.

The advantage of the short method over the Langley - Abbot method (spectro- bolometric) lies in the possibility of a number of independent measurements during the day. Owing to this, the changes of the transparency of the atmosphere during the day does not exert any important influence on the results.

At present, in order to obtain reliable values of the solar constant, it is determined daily at three stations of the Smithsonian Institution - on Montozuma Mountain (Chile), on Table Mountain (Calif)., and on Mount Brukkaros in South Africa.

§4 - The Measurements of the Ultra-Violet Radiation of the Sun.

A study of the data that was collected for many years by means of the spectro-bolometers at the stations of the Smithsonian Institution, has indicated large variations of the intensity of the violet part of the solar spectrum. Several investigators have organized special observations for the study of this phenomenon, and particularly interesting material was collected by E. Pettit at the Mount Wilson Observatory in 1924 and later. These observations are a part of the program of that observ tory and are performed every clear day.

For the observations of the variations of the intensity of the ultraviolet radiation, Pettit used a thermo-element. The observations consist of a comparison, at various zenith distances of the Sun, of the intensities of the solar radiation that was passed respectively, through thin silver and gold foil, applied to quartz plates. These metallic filters, that have proved to be very stable separate the solar spectrum, into two sections centering at about 3200Å and 5000Å respectively.

The computed ratio of intensities, for different masses of air penetrated by the radiation, is extrapolated, graphically, beyond the limits of the atmosphere. At first, these measurements exhibited variations of over 80°/o. of this ratio, but the later observations, made with improved apparatus, have reduced these variation to less than 17°/o. The problem whether these variations are due to actual changes taking place on the Sun, or are due to some changes of the terrestrial atmosphere, is still not solved finally.

2 - The Visual and Photographic Observations of the Surface of the Sun.

§5 - Observations of the Sun with a Refractor. The Photoheliograph

Owing to the great brilliancy of the Sun, the observations of its surface present great difficulties. In visual observations it becomes imperative to reduce the brightness of the Sun many times. Usually, a plate of dark, neutral glass is employed, which passes a small part of the light that falls upon it. This method of observations requires severe diaphragming of the

telescope, in order to avoid the extreme heating of the glass and its destruction. J. Hershel used a dark glass in a combination with a glass prism, the face of which reflected the light and weakened it to a great extent.

Other observers used special oculars - the helioscopes that achieved the reduction of light by the polarization of the light during reflections. The ocular helioscopes Colzi, manufactured by the Zeiss Company have received a wide distribution (see Fig. 67).

A glass mirror S is mounted before the focus of the telescope. The Sun's rays fall on this mirror, and being reflected, pass toward the double prism P_1 P_2. After a reflection from the common face of the prisms, the rays enter the ocular. The prism P_1 is made of crown glass, while the prism P_2 is liquid, and the coefficient of refraction of this liquid is a little less than that of the crown glass, which causes only a very small part of the light to be reflected by the face of the prism.

The method of projecting the image of the Sun on a screen is very extensively used. If R is the apparent angular radius of the Sun, r, the radius of the image of the Sun on the screen placed at a distance from the ocular, and w is the magnification of the telescope, then we can write the equation:

$$r = lw \operatorname{tg} R \sim \frac{lw}{215},$$

from which any one of these quantities may be computed if the others are known.

The method of projecting the Sun's image on a screen is very convenient for the determination of the positions of details on the solar disc, or for sketching them. If the screen is replaced by a photographic plate, photographs of the Sun's disc can be obtained. However, if the work is performed with a visual refractor, it is necessary to use green or yellow color filters and orthochromatic plates, as a sharp definition is otherwise impossible to obtain, due to the presence of a residual chromatic aberration of the objective (the secondary spectrum). The best results are obtained with special photographic instruments - the photoheliographs.

The photoheliographs are equipped with special objectives, consisting of a photographic objective O (Fig. 68) and a compound concave lens N. The photographic plate is placed at P, and a slit shutter, operated by a powerful spring is placed at V.

If f_1 - is the focal length of the objective Q, f_2 - is the focal length of the concave lens N, and e is the distance between the objective O and the lens N, then the equivalent focal length F of the objective and the total le length of the tube a, from the objective to the blate, can be found by the formula:

$$F = \frac{-f_1 f_2}{e - f_1 - f_2}; \quad a = F - \frac{e(f_1 - e)}{e - f_1 - f_2}$$

The distance e between the lenses is usually made larger by a few centimeters, than f_1+f_2. So, with $f_1 = 80$ cm and $f_2 = -15$ cm, e= 67 cm, the equivalent focal length will equal F=600 cm. With a tube only 165cm long an image of the Sun with a diameter of 6cm is obtained.

Fine -grain plates are used in the work with the photoheliograph, and particularly fine results are obtained with collodion plates. Owing to the exposures being of a duration of only a few hundredth parts of a second, the photoheliograph does not require any precise equatiorial mounting. Many astronomical observatories are equipped with photoheliographs and make systematic daily photographs of the Sun's surface.

§6 - The Heliographic Coordinates and Location of the Details on the Surface of the Sun.

An accurate determination of the position of the details on the surface of the Sun is a problem that is solved by these photographs. The position of the detail is determined by two coordinates, the heliographic latitude and the heliographic longitude . The heliographic latitude of the point is its angular distance from the solar equator, while the heliographic longitude is the angle between an arbitrarily chosen zeromeridian and the meridian passing through the given point.

The position of the solar axis of rotation in space has been determined by many astronomers. According to international agreement, the values determined by Carrington are universally accepted: the angle of inclination of the solar equator to the ecliptic = 7° 15'; the longitude of the ascending node =73°40' + 0°.014 (T-1850) (the second term accounts for precession); the time of sidereal rotation of the Sun around the axis =25.38 days; the zero meridian passed through the ascending node at Greenwich mean noon on Jan 1-1854.

Let r be the distance of the detail from the center of the image of the Sun's disc, and R be the radius of the image of the Sun's disc. In accurate determinations, both of these quantities are corrected for refraction. Also let be the angular distance from the apparent center of the disk, R', the angular radius, according to the data of the astronomical Almanac, and , the angle at the center of the Sun, formed by two directions: one to the Earth, and the other to the detail. Then

$$\rho' = \frac{r}{R} R \text{ and } \sin(\rho+\rho') = \frac{r}{R}$$

Also, let D (see Fig 69) be the heliographic latitude of the Earth (or of the apparent center of the Sun's disk), L, the longitude of the Earth in the accepted Carrington System, P, the position angle of the North Pole of the Sun, from the North point N, towards the East, p, the position angle of the detail M, and l, its longitude from the central meridian, that passes through the apparent center of the solar disc.

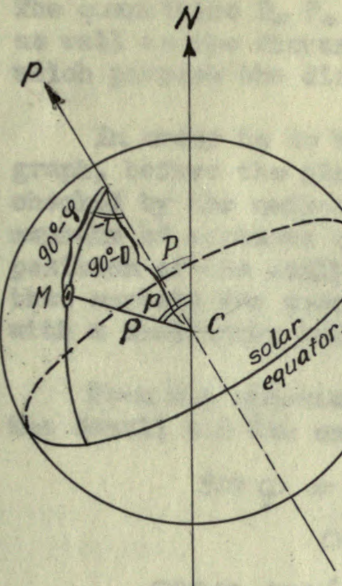


Fig. 69.

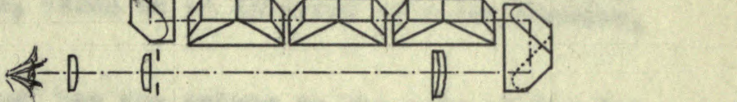
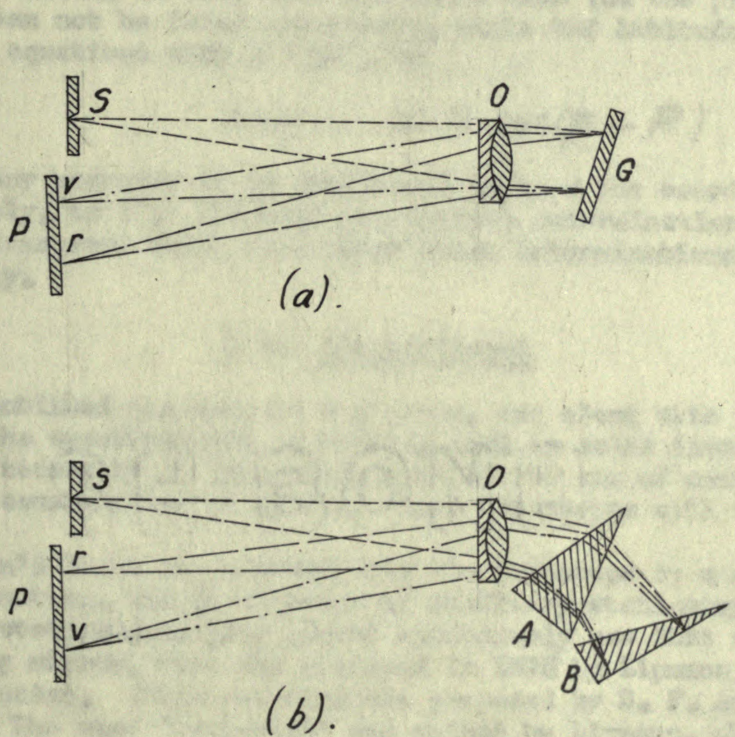


Fig. 72.



(a).

(b).

Fig. 73.

The quantities D, P, L are given in the Astronomical Almanacs, the angle p as well as the distance r and the radius R are measured on the plate, for which purpose the direction of the daily parallel is plotted on the image.

In order to do this, two fine cross wires are placed in the photoheliograph, before the plate, and the angular position of these is periodically checked by the method of transition of the Sun by these cross wires; the moments of contacts of the Sun's limb and the wires being determined. The position of the daily parallel can be also determined on these photographs, that contain two poctures of the Sun, taken at an interval of a few minutes, with a stationary tube.

From the spherical triangle, that has the apices at the pole of the Sun, the detail and the end of the solar radius pointing toward the Earth, we find:

$$\sin\varphi = \cos\rho \sin D + \sin\rho \cos D \cos(p-P);$$
$$\cos\varphi \sin l = -\sin\rho \sin(p-P);$$
$$\cos\varphi \cos l = \cos\rho \cos D - \sin\rho \sin D \cos(p-P).$$

These formula are used to compute φ and l. The longitude λ of the detail, in Carrington's system is found from the equation

$$\lambda = L + l.$$

If the detail is very near the Sun's limb (as the prominences), then the longitude can not be found accurately, while the latitude if found by the proceeding equations with $\rho = 90^\circ$, as

$$\sin\varphi = \cos D \cos(p-P)$$

For many purposes it is sufficient to know the coordinates of the detail approximately, to 1°. For such approximate determinations numerous tahles grids and nomograms exist that allow these determinations to be performed very rapidly.

§ 7. The Coelostat

The continued increase of the power, and along with it, of the size and weight of the spectroscopic apparatus, used in solar investigations, finally forced the necessity of discontinuation of the use of common refractors, and of the construction of special solar telescopes with stationary parts.

The Sun's light is directed into the telescope by a mirror that is rotated by a clock motion, and by a number of auxiliary stationary mirrors. At present, in solar investigations they almost exclusively use that form of mounting of the rotating mirror, that was proposed in 1895 by Lipmann, and which is known as the Coelostat. (This mounting was proposed by E. F. August in 1839, and by others. The name "Coelostat" was coined by Lipmann, who "re-invested" it).

The basic part of the coelostat is a plane mirror, rotating around a axis

with a velocity of one rotation in 48 hours. The axis of rotation is inclined, is oriented to the celestial pole, and is called the polar axis. The plane of the mirror must be strictly parallel to the polar axis. If the instrument is well mounted and regulated, and if we disregard such phenomena as refraction solar parallax etc, the reflected ray will remain in the same position in space.

The position of the reflected ray can be changed only in hour angle, while its declination will be always equal in quantity, and opposite in sign of that of the Sun.

There are two points of the horizon, placed symmetrically with respect to the meridian, where it is possible to direct the horizontal reflected ray. Their aziniuth α can be found by the formula

$$\cos \alpha = \sin \delta \sec \varphi ,$$

where δ is the ceclination of the Sun, and φ the latitude of the point of observation.

If the Coelostat is not regulated, the reflected ray will change its position, depending on the hour angle of the Sun. In order to adjust the position of the polar axis of the Coelostat, a small telescope, with a graduated declination circle is mounted on the axis. Thus the instrument becomes a small, parallactically mounted refractor, the position of whose polar axis is adjusted in the usual way, by observing the stars near the meridian and in hour angle near $\pm 6^h$ in the right and left positions of the declination circle.

If the plane of the mirror is not parallel to the polar axis, this can be discovered by a reversal of the position of the mirror on the bearings in such a way, as to cause the lower end of the axis to be placed on the upper bearing. During this operation, an observation is made through the telescope of the Sun's image reflected by the mirror in both positions. The angular displacement of the Sun's image after the reversal of the mirror equals twice the angle between the plane of the mirror and the polar axis of the Coelostat.

The adjustments of the mirror and of the position of the polar axis can also be made with a theodolite by observing the Sun directly and in the mirror of the coelostat.

As distinguished from other analogous apparatus using mirrors,(as the s siderostat and the heliostat), the coelostat produces a stationary, not rotating, image of the Sun. Owing to its geometrical simplicity, and to the stationary image, the coelostat has received a wide application in expeditional installations, in observations of solar eclipses, as well as in solar telescopes. In the latter case, the reflected ray is thrown in the same direction, independent of the declination of the Sun, by means of a second, auxiliary, mirror.

In order that the Sun's light, reflected by the coelostat mirror, may

fall upon the center of the auxiliary mirror, and the latter may not obscure the coelostat mirror, the mounting allows two, mutually perpendicular, movements of the mirrors - in the plane of the meridia, and in the plane of the prime vertical.

The Fig. 70 shows the coelostat with an auxiliary mirror, of the Snow Telescope of the Mount Wilson Observatory. The coelostat is mounted on a carriage, that has an East - West movement along the rails. The auxiliary mirror is also mounted on a carriage and can be moved along the optical axis of the telescope.

§ 8 - The Solar Telescopes.

The use of the coelostat has permitted large, stationary images of the Sun to be obtained under the laboratory conditions, and this made possible the use of a powerful spectroscopic apparatus such as in use by the physicists. Both the reflector and the refractor mounted stationary in a vertical or horizontal position, are used as an optical system to produce the image of the Sun. A vertical mounting with an objective seems to produce the finest images of the Sun.

The principal difficulties of the observations of the Sun are created by the ascending currents of warm air that rise from the warm soil, and by the distortion of optical parts of the apparatus from the heating by the Sun.

The vertical Solar Tower Telescope, that carries the coelostat and the objective high above the ground, is less subject, to the unfavorable action of the lower ascending currents, as those, rising from the ground, flow along the optical axis of the telescope. The telescope is protected from the side currents by the dome, inside of which the optical system is housed.

The direct heating by the Sun, affects the mirrors more seriously than the other parts of the telescope, as these suffer great changes of their surfaces. The plane mirrors become concave, shortening the focal length of the entire system by 1 meter, or more. The use of mirrors, made of Pyrax, whose coefficient of expansion is less than that of glass, decreases this distortion of the surface of the surface of the mirror several times.

Two vertical tower telescopes, first built by G. E. Hale at Mount Wilson Observatory, in California, have the respective heights of 20 and 50 m. The latter is shown in Fig. 71.

This telescope is equipped with several objectives, and produces an image of the Sun, up to 43 cm in diameter. Similar instruments are at Potsdam (Einstein-Turm) and at Florence (Arcetri).

The first large solar telescope, built by Hale at the beginning of this century, the Snow Telescope at Mount Wilson mentioned above, is an example of a horizontal, reflecting telescope. The image of the Sun obtained with this

instrument, are not as good as those obtained with the Tower Telescopes of the the same Observatory. In as much as a concave mirror is used to produce the image, the solar rays traverse a distance almost twice as long as in the case of an objective of an equal focal length.

Recently Hale constructed at Pasadena, a new vertical tower telescope with a Cassegrain mirror. By the introduction of different Convex mirrors, it is easy to change the equivalent focal length of the entire system, and thus obtain images of the Sun of different diameters. This type of mirror also considerably shortens the distance, traversed by the rays, which helps to improve the quality of the images. According to the available information the new Hale telescope gives fine results.

Solar telescopes, horizontal, or inclined, are also used in observing the total solar eclipses. Such horizontal telescopes, are usually equipped with a coelostat without any auxiliary mirrors. American Astronomers show a preference for an inclined mounting, directed to the point, where the Sun will be during the moment of totality. In order to obtain a stationary image of the Sun on the plate, during the exposure, that last of ten times several minutes, the objective, or the plate itself is given a corresponding movement, that compensates for the apparent diurnal motion of the Sun.

For studies of the fine details of the solar corona, that will be mentioned in the chapter on the Sun, telescopes of enormous focal length are sometimes used. Thus, the Lick Observatory uses in its expeditions for the observations of total solar eclipses, a telescope with a focus of 12 m, and an apperture of 1:96. The largest telescope was used during the eclipse of 1900 and had a focal distance of 41 m, with an apperture 1:135.

3. The Spectral Apparatus used in Studies of the Sun.

§9 - The Prominence Spectroscope

Soon after the discovery of spectrum analysis by G. Kirchhoff in 1859, the spectroscope was applied to the study of the spectra of the different details of the Sun. In 1868, during the total solar eclipse Jansen, and, independently Lockyer in England, demonstrated, that the spectrum of the solar prominences consists of several lines of such intensity, that they can be observed every day as such points of the Sun's limb, that have a prominence.

By recording the appearance of the spectral lines of the prominence with different positions of the spectroscope's slit, it is possible to obtain an idea of the size and the form of the prominence.

Huggins, Zellner and other investigators proposed in 1869 a new method of observations, that is still in use for visual observations of the prominence and the chromosphere.

If the slit of the spectroscope is placed tangent to the solar limb, and is opened wide, then, inside of the Hydrogen Line (the observations are usually made in the line H), an image of the prominence can be seen, projected against the dark lines of the spectrum of the sky. With a further widening of the slit, the image of the prominence dims and, finally, disappears. The optimum width of the slit is dependent upon the condition of the sky (with a whitest sky, the prominences are poorly visible), the quality and the dispersion of the spectroscope, etc.

By a record of the position of the point of contact of the slit with the Sun's limb at the point, where the prominence is observed, it is possible to determine the angular position of the prominence.

The height of the prominence is measured with the slit placed normal to the limb, and the readings are made with a micrometer screw, with which the spectroscopes are equipped. The height of the prominence is, sometimes, [illegible] measured by a glass scale, placed at the focus of the spectroscope's ocular.

The prominence spectroscope, used for observing the prominences consists of a small collimator, several direct vision prisms (Amicci) and a small telescope. The magnification of the entire telescope - spectroscope system can be determined by the formula

$$W = \frac{F}{f} w,$$

where F is the focal length of the telescope, f, the focal length of the collimator and w - the magnification of the ocular of the spectroscope. Fig. 72 shows a diagram of the Zeiss' Prominence Spectroscope.

§10 - The Solar Spectrographs

The growth of the solar telescopes in size was parallel to the growth of the power of the solar spectrographs and was forced by the latter. Astronomers have deserted spectrographs that were mounted on the telescope for stationary types. A distinguishing feature of the contemporary solar spectrograph is its high resolving power, with a relatively low light gathering power.

Just as the stellar spectrographs, so the solar ones can be divided into two types, depending on the optical system used to produce the spectrum. To the first and most commonly used type, belong the spectrographs with a plane reflecting diffraction grating and to the second type - the prism spectroscopes.

The production of good diffraction gratings and good glass prism of large sizes (about 10 - 15 cm), that are needed by the powerful spectrographs, is still subject to great mechanical difficulties, and therefore it is necessary to be content with the low light gathering power of the solar spectrographs. The majority of the solar spectrographs operate on the so-called auto-collimation principle. Fig. 73 gives the diagrams of a spectrograph with

a grating (fig. a) and one with prisms (fig. b).

The slit is at S, p - is the photographic plate, the letters v and r denoting the violet and red ends of the spectrum respectively, O is the objective that serves at the same time as the objective of the collimator and of the camera, G is a plane diffraction grating. By rotating it around an axis, parallel to the slit of the collimator, it is possible to project, upon the plate, the different parts of the spectra of various orders.

In Fig. 72b, A and B are two glass prisms. The back face of the prism B is silvered, which causes the ray of light pass twice through the both prisms.

The plate is customarily placed directly above the slit, in order to work near the main axis of the objective. The auto-collimatonal spectrograph produces a diffused light, due to the reflection of the slit from the surfaces of the objective. This can be avoided by either covering with black paper the corresponding parts of the objective, or by tilting the objective at such an angle, that the reflected light does not strike the photographic plate.

Both horizontal and vertical spectrographs are made at Mount Wilson Observatory, both tower telescopes are equipped with vertical spectrographs. The larger tower telescope is equipped with a spectrograph with an objective of a focal length of 23 m and a grating with an etched area of 67x126 mm, with 620 lines per milimeter. This spectrograph produces spectra up to 1 m. long with a dispersion of 1Å=5mm in the third order. All the apparatus is in a deep well under the tower telescope. The Potsdam and Pulkovo Observatories have horizontal spectrographs. The Pulkovo installation is shown in Fig. 74.

The focal length of the collimator of this instrument is 7m, the diffraction grating has an etched area 72x94mm with 589 lines per 1 min. In the third order, the dispersion of the spectrograph is 1mm=0.7Å.

For the adjustment of the position of the slit at any possible angle, as becomes necessary, for example, during the observations of the rotation of the Sun by the spectroscopic method, the spectrographs are contracted so, that they can be rotated around their axis. The Potsdam spectrograph is stationary, but the image of the Sun can be turned and kept at any position by a large reversing prism.

One of the most important problems of solar spectroscopy is the accurate comparison of the relative positions of the spectral lines on the opposite sides of the solar disc, at the limb and at the center etc. These problems are connected with the study of the rotation of the Sun by the spectrocoopic method. Also important is the study of different "effects", that will be mentioned later.

In the study of these problems, the photographs of the spectra of different parts of the solar disc are made simultaneously, one under another, on the same plate. The slit of the spectrograph is equipped with two pairs of totally reflecting prisms, that direct the rays from different parts of the solar disc to the corresponding parts of the slit. Finally, for the comparison of the solar spectrum with that of an artificial source (an electric arc), a separate optical system is installed, which allows, with the aid of mirrors, an image of the artificial reference light to be projected on the slit of the spectrograph, before and after photographing the solar spectra. This is necessary to eliminate the so-called, "pole effect", that is due to the fact, that different parts of the flame of the electric arc produce spectral lines of slightly different wavelengths. The central part of the flame is projected upon the slit of the spectrograph, and the negative electrode is made of carbon. In such a case the resultant spectrum is free of the pole effect.

As early as the end of the last century Rowland used concave diffraction grids, and photographed the solar spectrum up to 2975Å - the observable limits of it on the ultra-violet end. The use of special plates, sensitized to the infra-red rays permitted H. Babcock to photograph the solar spectrum to 11634Å. The photographing of the extreme ends of the solar spectra by means of powerful spectrographs require exposures of several hours duration, while the photographing of the visible part requires only a few minutes.

Owing to their great dispersion, the spectrographs allow very accurate determinations of the wavelengths of the spectral lines to be made by the use, of the standard lines, whose wavelengths are determined by an interferometer. So, for the big spectrograph of the Mount Wilson Observatory, the error of measurement of the wavelength of a single line, on a single plate, seldom exceeds 0.002Å. The precision of the measurements increases greatly for the measurements of the small displacements of the spectral lines, and for the 9 meter spectrograph is less than 0.0003Å, that is equivalent to an error of about 0.03 km/sec in the determinations of the radial velocities.

During the observations of solar eclipses, they often use spectrographs of great dispersion, with or without the slit, to study the spectra of the upper and middle layers of the solar atmosphere.

The plate holders of such spectrographs are their distinguishing part, as a quick change of the plates is essential. The plates are either mounted on a drum, the turning of which after every exposure allows a series of pictures to be made or the plates are mounted on a frame, and the same result is obtained by sliding it. Quite often the plates are replaced by films that are exposed, while stretched on a cylindrical surface, computed to bring into sharp focus the greatest part of the spectrum.

Also of great interest are the photographs of the solar atmosphere made, at the beginning or at the end of the totality phase, with a slitless spectrograph. On such photographs the spectral lines assume the shape of sickles of different lengths and intensities, that really are the monochromatic images

of the solar atmosphere, partially obscured by the lunar disc. By measuring the length of such a sickle, it is possible to find the altitude that is reached by the atoms of the given element, at the given state of the atmosphere.

Outstanding results were obtained by S. A. Mitchell in 1905 and 1925 with the metallic concave diffraction grids. In 1905 Mitchell used a 10 cm concave grid of 3m. radius. The photographic film was stretched on a concave cylindrical surface, that was placed at a distance of $1^1/2$ m. from the grid The spectrograph was mounted stationary, and the Sun light was directed by a coelostat.

A great difficulty is presented by the focusing of the spectrograph, as the position of the focus changes noticeably as a result of the distortion of the form of the coelostat mirror and of the grid, under the influence of the heating by the solar rays. The focusing is done at night, by the stars, or by a special collimator. Mitchell was able to overcome these difficulties in 1905, and he has obtained a beautiful spectrum 23.5 cm long, extending from 3318Å to 5876Å. Unfortunately, during the eclipse of the 1925, the spectrum was a little out of focus.

Photographs made with the slit spectrographs are also used in the studies of the same problem of the distribution of the chemical elements in the layers of the solar atmosphere. In this case, during the exposure, the plate is moved slowly by a small electric motor. On such photographs, different spectral lines are of different heights; by measuring the apparent height of a line; it is possible to compute the altitude that is reached by the atoms of the element that forms this particular line.

§ 11 - The Spectroheliograph.

The improvements of the technique of solar observations are, to a great degree, due to that interest in studies of the solar prominences, that was exhibited by astronomers after the invention of methods of their observations, independent of solar eclipses. As we have already mentioned, the first method of observation of the prominences proposed by Jansen and Lockyer, consisted in recording on sketches of the length of the bright Hydrogen line H_2, at different positions of the slit.

Zoellner and C. A. Young expressed thought, that by giving the slit a rapid oscillating motion, it is possible to obtain a complete picture of the whole prominence. However, a simpler method of the observation of prominences with a wide slit, proposed by Huggins and Zoellner in 1869 arrested the development of the first method by more than a half a century, when Hale, utilizing this principle, constructed the spectrohelioscope, an apparatus that became, later, widely employed, and that we shall describe later.

In 1874 Young obtained the first photograph of prominence in the line H on collodion plates, with the slit of the spectroscope open wide. Hale

continued Young's experiments of photographing the prominence, and, at the nineties of the last century, achieved good success.

In 1889 Hale invented a spectroscope with two moving slits - the spectroheliograph. Almost simultaneously, and independent of him, the spectroheliograph was invented by H. Deslandre and I. Evershed. It should be noted, that even before that, Jansen in 1869 and, independently C. Braun in Kaloch Hungary, in 1972, and finally O. Lohse of Potsdam in 1885 proposed the construction of such an instrument, Lohse even actually constructed one, but obtained no results, due evidently to an insufficient sensitiveness of the collodion plates he was using.

At present, the spectroheliograph is a basic instrument of every observatory, that conducts systematic studies of the Sun. The principal part of the spectroheliograph is a monochromator spectroscope, that allows to be isolated a very narrow part of the solar spectrum. The image of the Sun is projected upon the first slit of the spectroheliograph. The second slit is placed at the focus of the camera, and the spectrum is projected upon it. This slit passes a narrow part of the spectrum, that is photographed on the plate, placed directly behind the second slit.

If we shall move the image of the Sun on the first slit, we will obtain, consecutively, the spectra of the new portions of the solar surface. If, simultaneously with the movement of the solar image across the slit we move the photographic plate, we will obtain a monochromatic photograph of the Sun in the wavelength of that part of the solar spectrum, that was cut out by the second slit. The obtained image is a series of consecutive images of the second slit, illuminated by the rays of a same wavelength, radiating from the different parts of the solar disc. Especially interesting photographs are obtained, when a prominent Frannhofer line is isolated by the second slit.

At present, many foreign observations conduct systematic photographing of the Sun in the lines of ionized Calcium K and of Hydrogen Hα. The daily photographs of the prominences are made in the same line, for which purpose the image of the solar disc is obscured by an opaque screen that is moved along with the image of the Sun.

The modern spectroheliographs are constructed, generally, in two types: 1) the spectroheliographs with a stationary image of the Sun and photographic plate, and movable spectral parts and 2) the spectroheliographs with movable image and plate, and stationary spectral parts. The more powerful spectrographs belong to the second type.

Fig. 75 shows the diagram of the Potsdam spectroheliograph, that is of the first type. The spectral parts of the apparatus are mounted on a metallic frame TT, that moves on rollers within an outer frame. The movement is effected by a suspended weight, that acts upon the frame TT through a system of pulleys. The velocity and the uniformity of the movement is regulated by a water clock (clepsydra) filled with a solution of the glycerine in water. Fig. 75c shows the collimator, K is the camera, S_1 and S_2, two similar objectives, - G the grid, that is used in the fourth order, in a combination with a plane mirror and a rectangular prism.

The Potsdam spectroheliograph is disigned to be mounted on a refractor with a 21cm objective and a focal length of 3.2m, that produces an image of the Sun in 30 mm dia. For obtaining the exposed photographs of the Sun in the line K of Calcium, on plates of a medium sensitivity, the exposure lasted 1 minute.

Fig. 76 shows the 1.5m. spectroheliograph of the Mount Wilson Observatory, belonging to the first type, and used in conjunction with the Snow Telescope.

Fig. 77 shows the diagram of the large spectroheliograph of the Meudon Observatory, that is probably, the most perfect instrument of this kind.[1] This spectroheliograph is placed horizontally, is stationary, and belongs to the second type. The instrument may be used, at will, with prisms, or gratings.

The solar ray is reflected by two mirrors of a coelostat upon a 25cm objective O_p with a focal length of 4 m. This objective is mounted on a carriage, that can move uniformly, in the direction perpendicular to the optical axis. The movement of the carriage is effected by the electric motor m, whose transmission gear is equipped by a speed regulator t, that allows a great range of speeds, that may be used in moving the objective.

Along with the movement of the objective, the resultant 36 mm image of the Sun also moves across the slit F of the collimator C, upon which it is projected. The pencil of rays, after leaving the objective O of the collimator, falls upon the diffraction grating R, or if this is slid out of the way, upon the prisms P.

In the first instance, when the grid is used, the spectrum is received by the objective O_2 in the camera II and the needed part of the spectrum is cut out by the second slit F_2. In the second case, the spectrum is formed in the camera I, equipped with the secondary slit F_1. The pole holders, during the operation of the spectroheliograph are moved by the motor m, that is worked also with the speed regulators t. The revolutions of these motors are electrically synchronized with the revalutions of the motor, that moves the objective O_p. The speed regulators also have to be adjusted, so as to obtain a round image of the Sun.

The Objective O_1 of the camera I can be replaced by a plane mirror M1, and the apparatus may work by a third method, with the objective O'_1 and the camera III, with the secondary slit F_3. The instrument can be operated in a fourth way, if the objective O'_1 is taken out. In this case, the ray, separated into the basic parts and reflected by the mirror M_1, strikes the concave mirror

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1. 1) A similar instrument was recently installed in the Portugese Observatory at Coimbra.

M_2, placed in the camera IV, that forms the image of the spectrum upon the plane of the slit F4, that separates the needed part of the spectrum. Finally, the apparatus operates in a fifth way, when it is necessary to obtain f especially sharp spectroheliograms, as far as possible free from the effect of the diffused light in the spectrograph. In such a case, the rays, reflected by the mirror M_1, fall upon the concave mirror M_2. As in the case of the proceeding scheme, the slit F4 cuts out the needed part of the spectrum. After passing through this slit, the rays fall upon another parallel; then they fall upon the prism p', that directs them into the camera IV-bis. The image of the spectrum is obtained, at will, by either objective O_5-O6 (The other objectives are removed) upon the third slit of the spectroheliograph f, that eliminates the diffused light of a different wavelength, that was refracted by the prism p'.

The plateholder, placed beyond the slit f, can be moved uniformly at a needed speed, by a synchronized electric motor m, that acts, as in other cases, through a speed regulator t.

This speed regulator is constructed thus; between two flat discs, rotated in opposite directions, by the motor, is a wheel with a sharp edge, whose axis is parallel to the radii of the discs. The rotation of the discs is transferred to the wheel, the velocity of whose rotation can be regulated through a wide range, by changing its position closer to or farther from the axis of the dises.

It is well known, that the prism spectrograph produces curved, parabolic spectral lines. In the spectroheliographs the heigh of the slit is made big enough to photograph the entire solar disc in one operation, and therefore the secondary slit of the spectroheliograph is made curved, in order to separate the lines across the whole width of the spectrum. However, photographing the Sun with a straight slit on the collimator and a curved slit on the camera, would result in a distorted image of the Sun, and in order to avoid this distortion, both slits are given an similar mean curvature. A special pair of slits is used for every part of the spectrum, as the degree of the curvature depends on the wavelength of the particular part of the spectrum.

In the diffracted spectrum the lines have a very low degree of curvature, and quite often, straight slits are used with the diffraction grid. In the Meudon Spectroheliograph, during operation by the fourth and the fifth methods, the dispersion reaches 0.7Å per 1 mm for the prisms and 2.Å for the grid when the K line of Calcium (3934Å) is separated, and respectively 4.1A per 1 min and 1.8A with the Hydrogenline Hα (6563Å). With this instrument it is possible to separate parts of the different spectral lines, by opening the secondary slit only 0.05Å.

At Meudon, the daily, systematic photographs of the solar surface are made in the middle parts of the lines Hα of Hydrogen and K of Calcium, the

diameter of the image being about 9 cm, and with an exposure of several minutes.

Along with all its good qualities the spectroheliograph has two important disadvantages. Owing to a comparatively long exposure the spectroheliograph does not allow those solar phenomena to be observed in detail, that last sometimes only a few minutes, and whose radiation is of a special interest. In as much as the spectroheliographs separate only a very narrow part of the spectrum, many solar phenomena, that have a large radial velocity, will miss the secondary slit, owing to the Doppler Shift, and will remain unregistered. In both cases these phenomena can be observed by special apparatus, to whose discription we shall turn now.

§12 - The "Spectro-Enregisteur des Vitesses"

If we cause the image of the Sun and the photographic plate to move by jerks relative to the both slits, we shall have the apparatus, invented of Deslandres before the invention of the spectroheliograph, and that he called "Le Spectro-Enregisteur des Vitesses". The secondary slit of this apparatus is made wide enough to form an image of the entire line, and of the adjoining parts of the spectrum. The length of the "jerks", or the distance by which the solar image and the plate are moved, after the exposure, are chosen to correspond to the width of the secondary slit. The resultant image of the Sun consists of adjoining strips, each of them being a photograph of a part of the spectrum, that was cut out. In each strip, it is possible to measure the shift of the central line, relative to the adjoining spectral lines, or relative to the edges of the strip, and thus to compute the relative radial velocities of the different formations on the surface of the Sun. In order to determine the absolute velocities, photographs of the same spectral line are made in the spectrum of a terrestrial source of light, before and after the solar photographs are made. The position of this line, (in the spectrum of the terrestrial source of light) is determined relative to the edge of the strip.

Fig. 78 shows, greatly magnified, the photographs of a part of solar surface, obtained by the Meudon spectro-register of velocities. These pictures show plainly the curving and the distortion of the spectral line in several places of the solar surface. The left picture is that of the line K of Calcium, and the right - the line $H\alpha$ of Hydrogen.

Disregarding the good results obtained by Deslandre in his studies of the radial velocities of the solar surface, the spectro-register of velocities did not come into a general use. There is no doubt, that its use in the studies of the radial vlocities of the formations on the solar surface as well as its wide application to the problems of spectrohotometry, could furnish very valuable data, as was recently pointed out during one of the sessions of the International Astronomical Union.[1]

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[1] The solution of many problems of solar physics makes it desirable to be able to obtain, simultaneously, two pictures in any two parts of the spectra, by

the same collimator. Such an instrument should work as a double spectroheliograph and as a spectro-register of the volocities. An instrument of this discription was constructed by Hale, Julius and D'Asambuja, but without any special success.

In 1931 Peropelkin of the Polkovo Observatory proposed a new principle, that solves completely the problem of constructing such an instrument.

The apparatus consists of a diffraction spectrograph with one collimator, but two cameras. One of these works with the right spectrum of the diffraction grating, while the second with the left. The construction of this apparatus demands a diffraction grating, that produces equally good right and left spectra. The Pulkovo Observatory has begun the erection of this apparatus. It is being designed by N. G. Ponomareff of the Leningrad Astronomical Institute, under the supervision of the author of the project. The Soviet Union Collective of the Optico-Mechanical Industry (BOOM) has undertaken the construction of the optical system of this apparatus. The mechanical and electrical parts are to be constructed by the same organization in collaboration with the mechanical shops of the Pulkovo Observatory.

This solar telescope will act as 1) a double spectrograph of large dispersion, 2) as a double spectroheliograph, 3) a double spectro-register of velocities and 4) as a double spectrohelioscope, that will allow separation of any two different parts of the spectrum.

This apparatus will allow for the first time, to the rapid development of the solar eruption in any two parts of the spectra to be studied at the same time, as for example, in the lines of Calcium and Hydrogen.

This instrument will enable the detailed structure of small solar formations to be studied, also in any two parts of the spectra, simultaneously, as in this case, as long as a single collimator is used, the variations of the solar image will affect, almost alike, both parts of the spectrum.

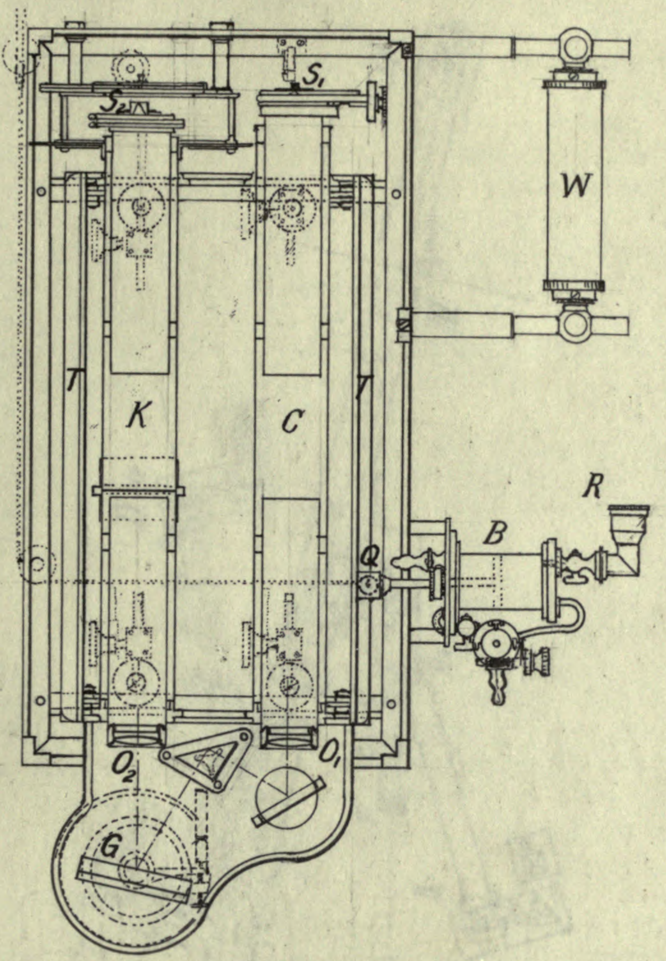
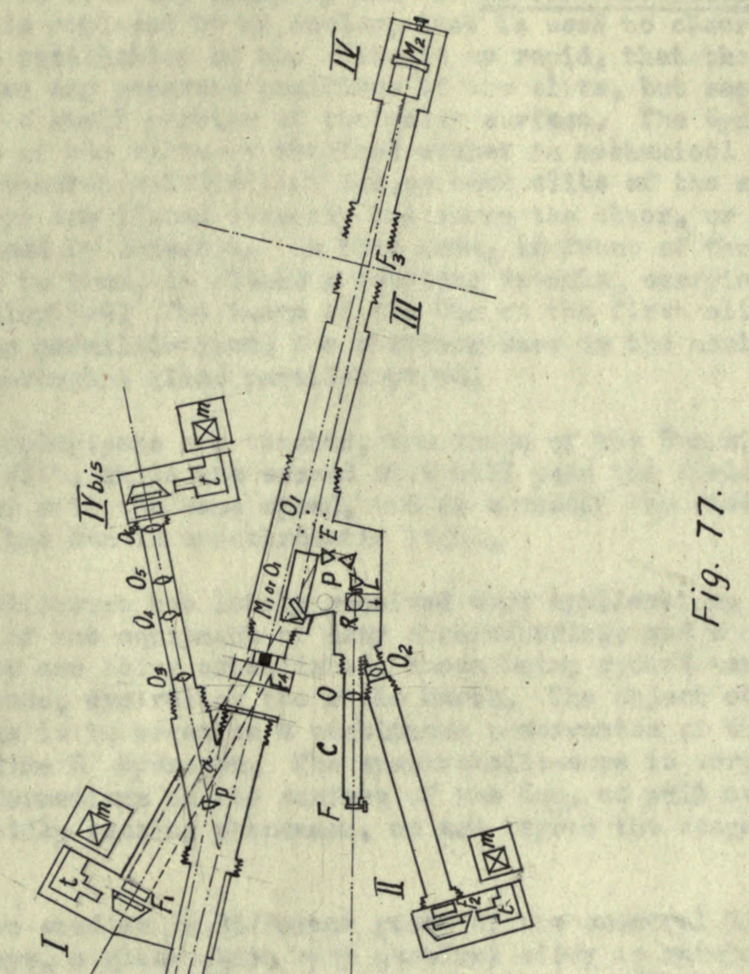


Fig. 75.


IV
M2
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O3
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M1 or O1
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Fig. 77.

13 - The Spectro-helioscope

If we will cause the both slits of the spectro-heliograph, to vibrate quickly, while the solar image remains stationary, we will have an apparatus, constructed by Hale in 1924 and named by him the Spectro-helioscope. The photographic plate is replaced by an ocular, that is used to observe the solar surface. The oscillation of the slits is so rapid, that the eye of the observer does not see any separate positions of the slits, but sees, in monochromatic light a small portion of the solar surface. The Synchronization of the oscillations of the slits is attained either in mechanical ways, that do not present any theoretical difficulties,as both slits of the auto-collimational spectroscope are placed directly one above the other, or by optical means, as was proposed by Anderson. In this case, in front of the stationary slits, and parallel to them, is placed a rotating spindle, carrying on each end a glass parallelopiped. The image of the Sun on the first slit is obtained through the glass parallelopiped; the observer sees in the ocular the second slit, also through a glass parallelopiped.

When the parallelopipeds are totated, the image of the Sun will pass quickly across the slit, while the second slit will pass the field of vision of the ocular with the same speed, and as a result the observer will see the surface of the Sun in monochromatic light.

The spectro-helioscope has lately received wide application. This instrument is a part of the equipment of many observatories, and a number of observation stations are being established, these being spaced more or less regularly in longitude, encircling the whole Earth. The object of these observation stations is to organize a continuous observation of the surface of the Sun in the line H Hydrogen. The spectrohelioscope is very convenient for observing all formations on the surface of the Sun, as well as the prominences and such rapidly passing phenomena, as are beyond the scope of the spectroheliograph.

For comparative studies in different parts of the spectral line in the direction of the rays, a glass plate with parallel sides is mounted, in front of the secondary slit, and is rotated around an axis, parallel to the slit. In its different positions, this plate will separate, the different parts of the line. This appliance also allows to the relative radial velocities to be computed by a measurement of the angle of the plate, at which the given solar formation is seen best. Thus the spectrohelioscope includes in the scope of its possibilities certain functions of the spectroheliograph and of the spectro-register of velocities.

The application of the motion picture camera, without any doubt, will

enlarge the field of application of this apparatus still further. In 1933 the Michigan University Observatory in the U.S.A. constructed the first spectroheliocinematograph.

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